U.S. DEPARTMENT OF ENERGY | Nuclear Energy

Informing Long-Term Operation of US Plants: the Department of Energy Light Water Reactor Sustainability Program

Kathryn A. McCarthy, Ph.D.

Director, Light Water Reactor Sustainability Technical Integration Office

Idaho National Laboratory

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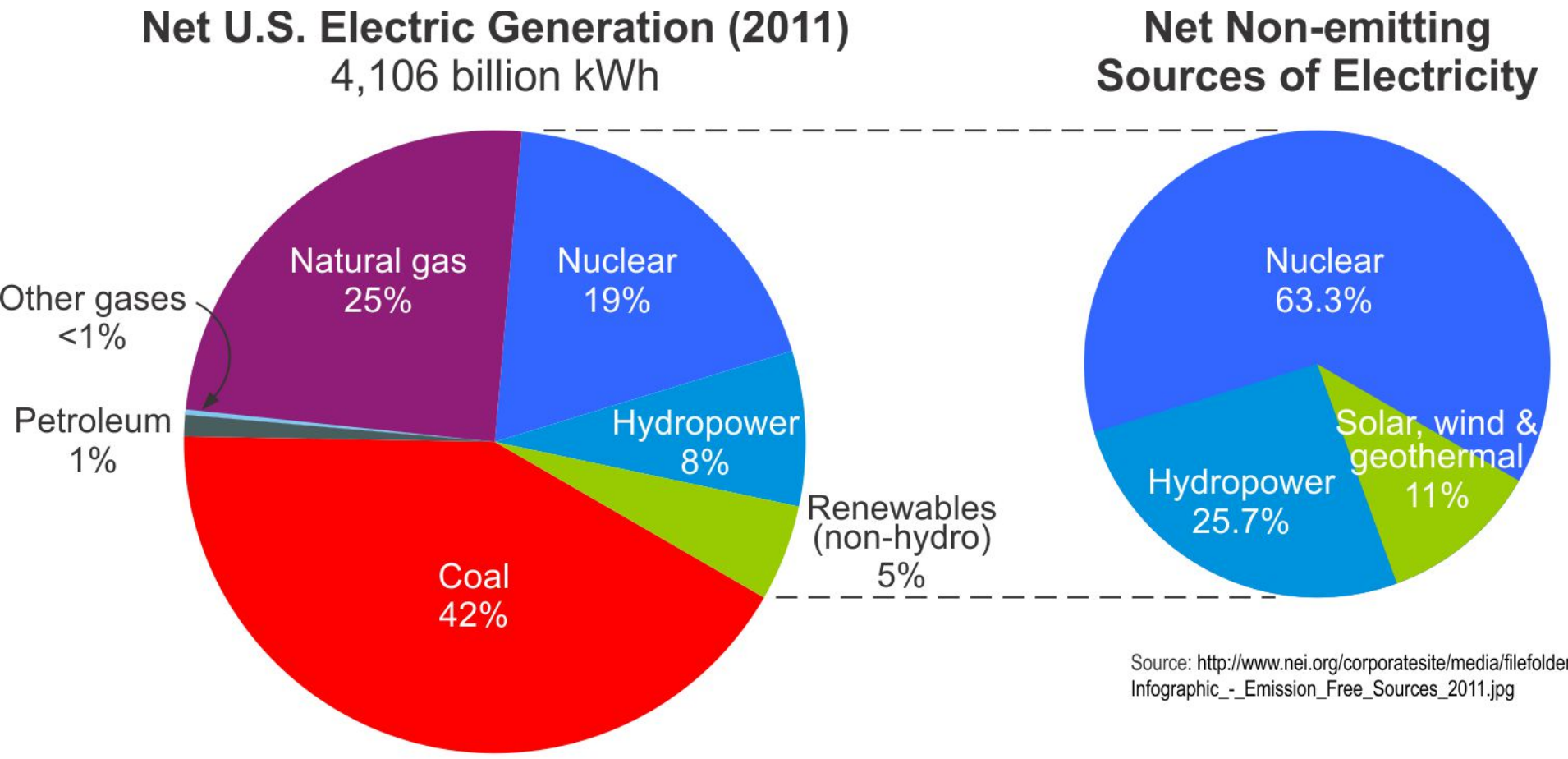
Outline

- License Period for US Reactors
- Motivation for US DOE Light Water Reactor Program
- LWRS Program Goals
- LWRS Program Coordination and Collaboration
- LWRS Program Technical Plans and Selected Results

License Period of US Reactors

- **The 40-year initial operating license period established in the Atomic Energy Act was based on antitrust and capital depreciation considerations, not technical limitations**
- **The 20-year license extension periods are presently authorized under the governing regulation of 10 CFR Part 54, "Requirements for Renewal of Operating Licenses for Nuclear Power Plants"**
  - This rule places no limit on the number of times a plant can be granted a 20-year license renewal as long as the licensing basis is maintained during the renewal term in the same manner and to the same extent as during the original licensing term (e.g., the licensee can demonstrate continued safe and secure operation during the extended period)
- **The license extension applicant must demonstrate how they are, or are planning to be, addressing aging-related safety issues through technical documentation and analysis, which the U.S. Nuclear Regulatory Commission (NRC) confirms before granting a license extension**

Nuclear Energy is the Largest Source of Non-emitting Electricity in the U.S.



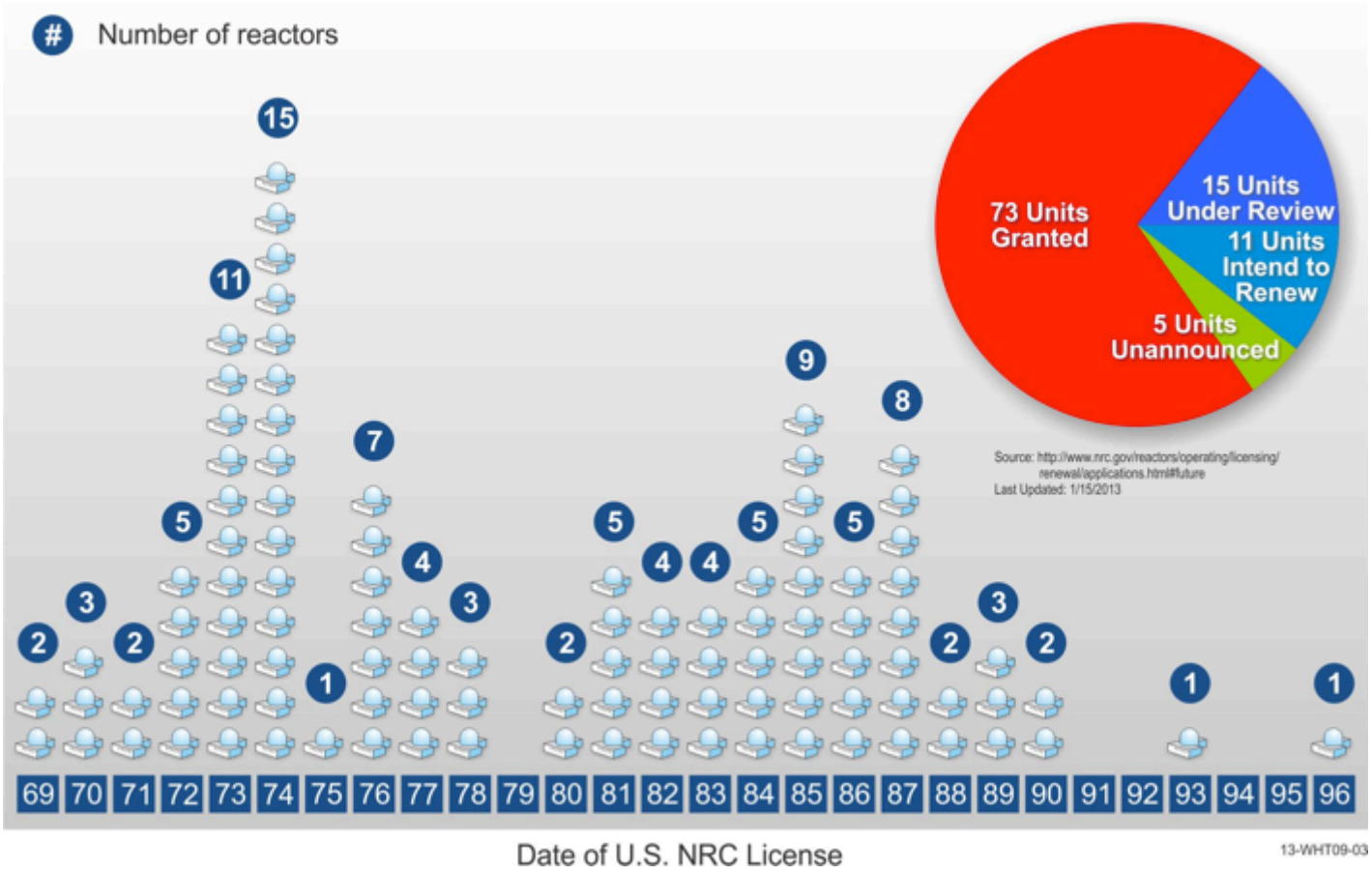
Source: http://www.nei.org/corporatesite/media/filefolder/Infographic_-_Emission_Free_Sources_2011.jpg

Source: http://www.eia.gov/tools/faqs/faq.cfm?id=427&t=3

13-WHT09-01

Extended Operations of the Existing Reactor Fleet is in the U.S. National Interest

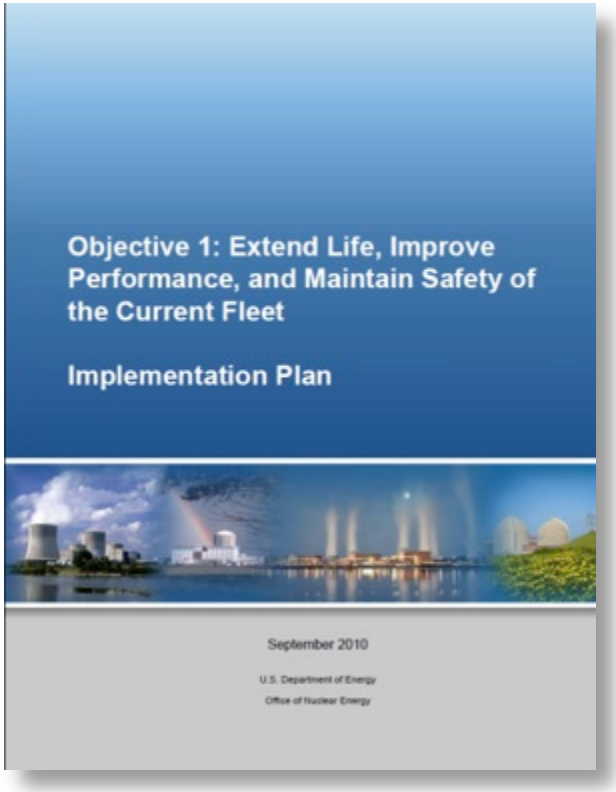
- US LWRs are a national asset: without today's LWRs, we lose:
  - ~100 GWe of low-carbon generation over about 20 years
  - Low-cost generation
- It is unlikely that new plants can be built quickly enough to both replace LWR retirements and meet demand for new clean electricity



Note: This graphic does not reflect the recent decisions to retire Crystal River, Kewanee, SONGS, and Vermont Yankee

Light Water Sustainability Program Goals and Scope

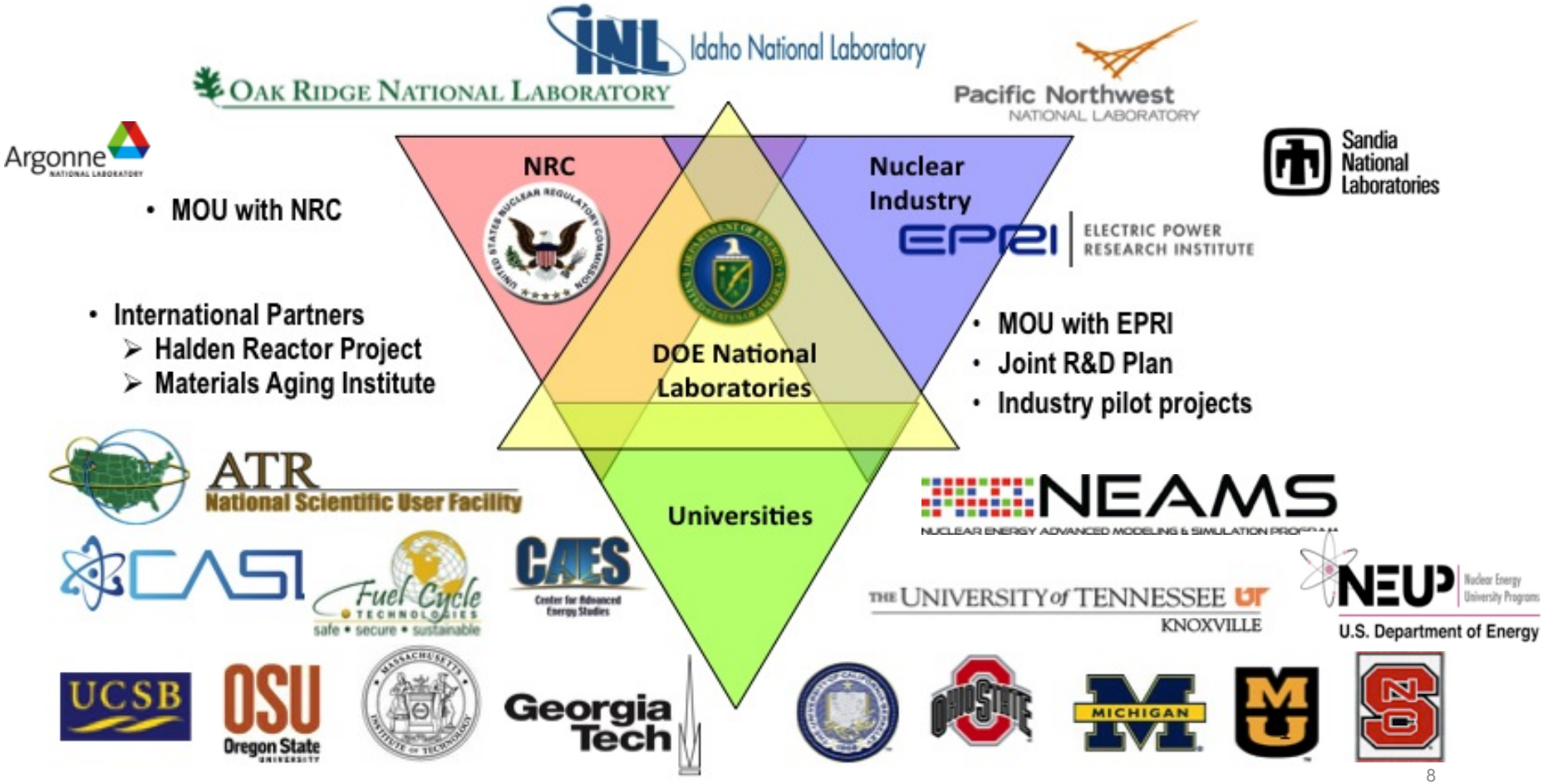
- **Develop the fundamental scientific basis to understand, predict, and measure changes in materials and structures, systems and components (SSCs) as they age in environments**
- **Apply this knowledge to develop and demonstrate methods and technologies that support safe and economical long-term operation of existing reactors**
- **Researching new technologies that enhance plant performance, economics, and safety**
- **Scope**
  - Materials Aging and Degradation
  - Risk-Informed Safety Margin Characterization
  - Advanced Instrumentation, Information and Control Systems Technologies



Light Water Reactor Sustainability Program – the Federal Role

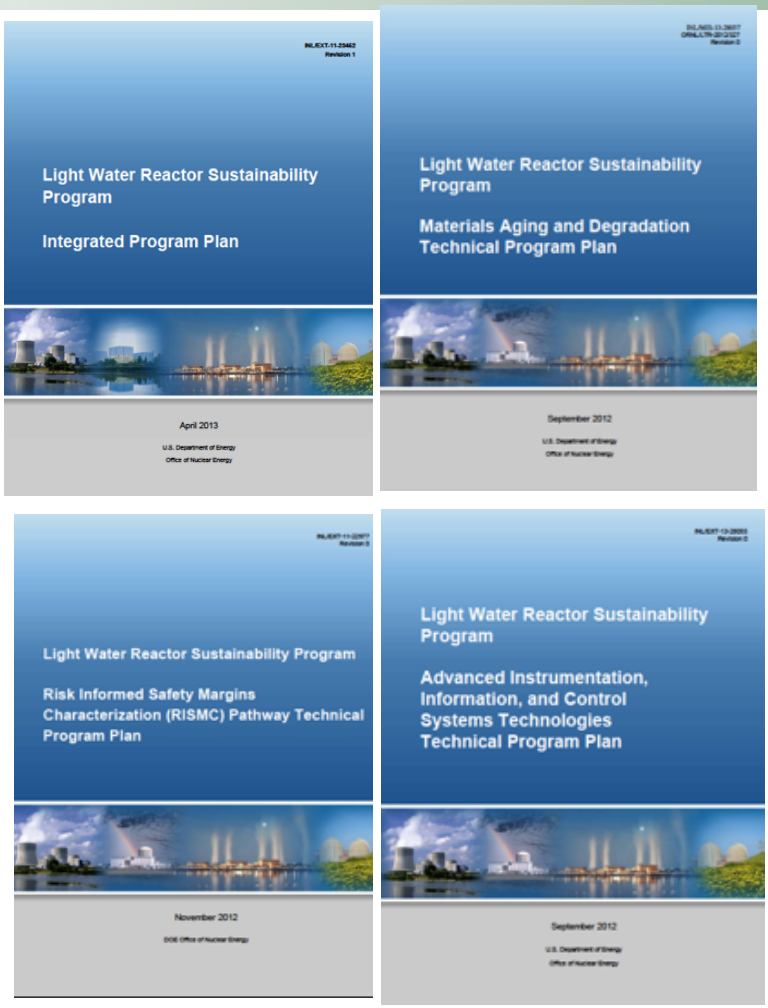
- National strategic interest in the long-term operation of existing plants
  - Supports climate change objectives
  - Supports energy security
  - Avoids higher cost to ratepayers for new plant replacements
- Cost-sharing is being employed through cooperative research activities with industry, primarily the Electric Power Research Institute (EPRI)
- Addresses fundamental scientific questions where private investment or capabilities are insufficient to make progress on broadly applicable technology issues for public benefit
- Government (DOE and its national laboratories) holds a large theoretical, computational, and experimental expertise in nuclear R&D that is not available within the industry
- Benefits will extend to the next generation of reactor technologies being deployed and still in development
- Federal program creates an environment (by reducing uncertainty and risk) that provides incentives for industry to make the investments required for power operation periods to 60 years and beyond

R&D Coordination and Collaboration is Essential to LWRS Program Success



Program Plans are Documented in the LWRS Program Integrated Program Plan (IPP) and Pathway Technical Plans

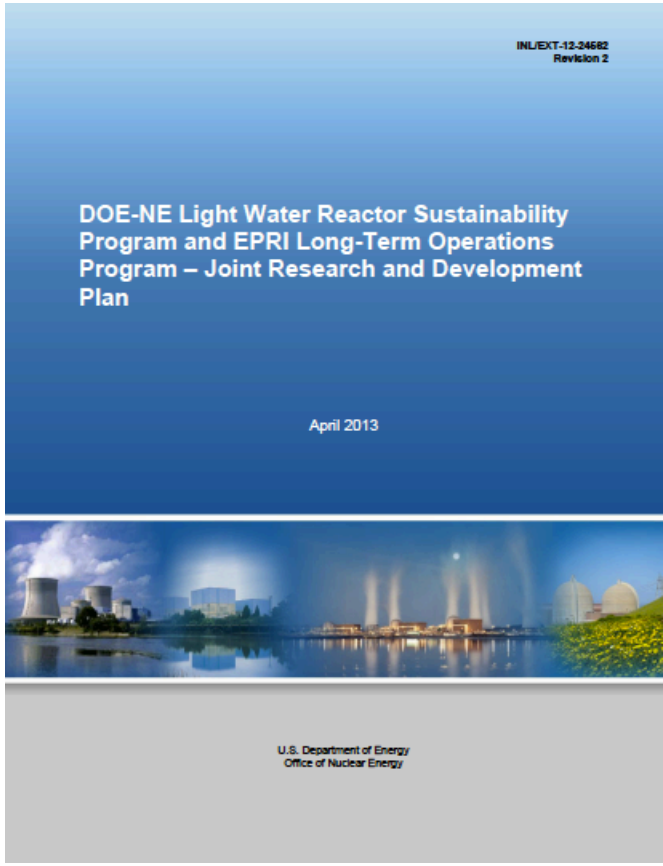
- **The IPP Includes clear and realistic R&D goals and objectives, deliverables, industry interactions and technology transfer plans for each pathway**
  - Based on expected federal budgets of approximately $25M
  - Program and pathway objectives
  - Pathway technical plans
  - Major milestones with an emphasis on 2013-2017
  - Coordination and collaboration with stakeholders
- **The IPP is updated annually**
- **Pathway Technical Program Plans include more detailed information for each pathway (also updated annually)**



Program Plans Are Available on www.inl.gov/lwrs

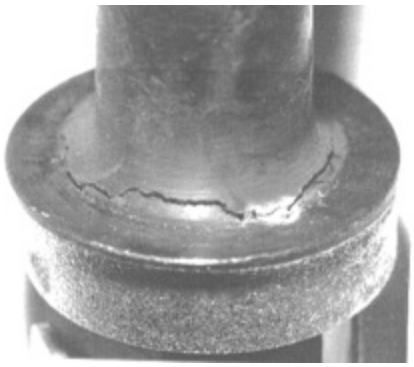
DOE-NE LWRS Program and EPRI LTO Program – Joint R&D Plan

- **The DOE LWRS and EPRI LTO Programs are separate but complementary**
- **Provides for the integration of the separate LWRS and LTO Program Plans at the project level**
  - Schedule, budgets, and key interrelationships between the LWRS and LTO programs
- **Two categories of work are described**
  - Coordinated Activities
    - *Managed by either DOE or EPRI*
    - *Coordination will be limited to joint planning and communications to limit possible overlaps and gaps that may exist in the planned activities*
  - Collaborative Activities
    - *Planned and executed on a collaborative basis*
    - *Efforts may involve, to a significant degree, joint funding as permitted by law and available appropriations*
    - *DOE and EPRI will determine which organization will lead each effort based on which party is positioned to most efficiently and effectively execute the work*
- **Report includes a brief summary of the R&D activities**



Materials Aging and Degradation Pathway

- **Increased lifetime leads to increased exposures**
  - Time at temperature
  - Stress
  - Coolant
  - Neutrons
- **Extending reactor operation beyond 60 years may increase susceptibility and severity of known forms of degradation**
- **New mechanisms of materials degradation are possible**



- **Develop the scientific basis for understanding and predicting long-term environmental degradation behavior of materials in nuclear power plants**
- **Provide data and methods to assess the performance of systems, structures, and components essential to safe and sustained nuclear power plant operations**
- **Develop means to detect and characterize aging degradation processes**

Materials Aging and Degradation Tasks Provide Results in Several Ways

- ***Measurements of degradation:*** High quality data will provide key information for mechanistic studies and has value to regulators and industry
- ***Mechanisms of degradation*:** Basic research to understand the underlying mechanisms of selected degradation modes will lead to better prediction and mitigation
- ***Modeling and simulation*:** Improved modeling and simulation efforts have great potential to reduce the experimental burden for life extension studies. These methods can help interpolate and extrapolate data trends for extended life
- ***Monitoring*:** Non-destructive monitoring techniques support surveillance programs
- ***Mitigation strategies*:** While some forms of degradation have been well-researched, there are few options in mitigating their effects. New technologies may overcome limits of degradation in key components and systems

Materials Aging and Degradation Research Areas Were Identified Based on Stakeholder Input

- **Reactor Metals**
  - High Fluence Effects on RPV Steels
  - Material Variability and Attenuation Effects of RPV Steels
  - Nondestructive Evaluation of RPV Degradation
  - Mechanisms of Irradiation-Assisted Stress Corrosion Cracking
  - High Fluence Irradiation Assisted Stress Corrosion Cracking
  - High Fluence Phase Transformations of Core Internal Materials
  - High Fluence Swelling of Core Internal Materials
  - Cracking-Initiation in Ni-Base Alloys
  - Nondestructive Evaluation of Cracking Precursors
  - Environmentally Assisted Fatigue
  - Nondestructive Evaluation of Environmentally-Assisted Fatigue Degradation
  - Thermal Aging of Cast Stainless Steels
- **Concrete**
  - Concrete and Civil Structure Degradation
  - Nondestructive Evaluation of Concrete and Civil Structures
- **Cables**
  - Mechanisms of Cable Insulation Aging and Degradation
  - Nondestructive Evaluation of Cable Insulation
- **Buried Piping**
  - No Activities Planned Currently (large industry program underway outside of LWRS Program)
- **Mitigation Technologies**
  - Advanced Weld Repair
  - Advanced Replacement Alloys
  - Thermal Annealing

Example Results Are Included in this Presentation

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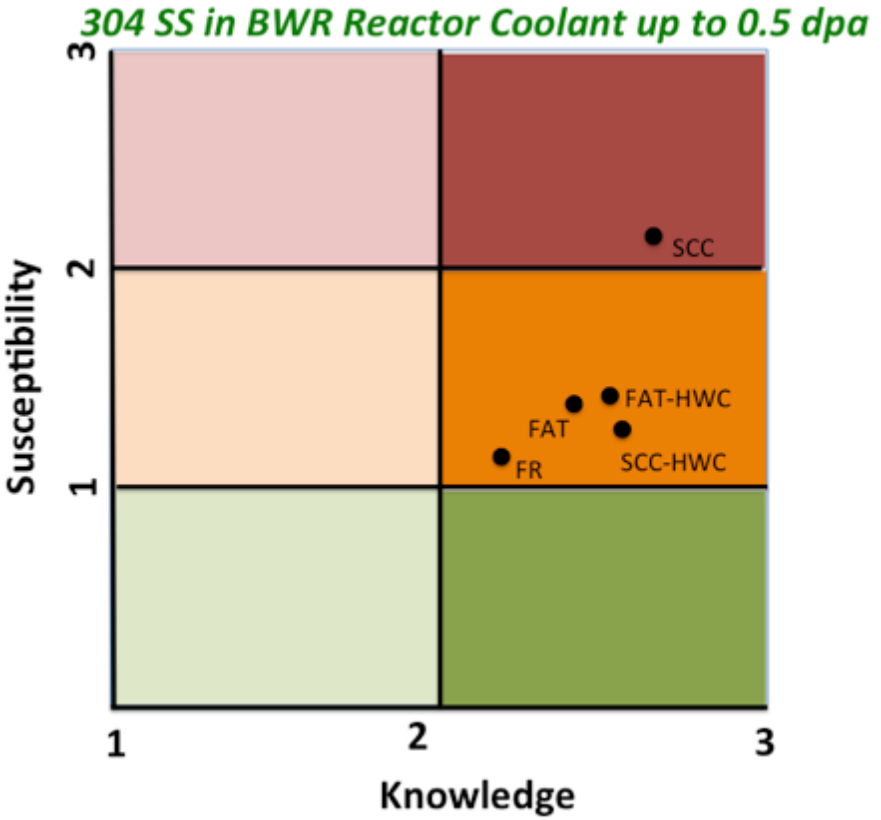
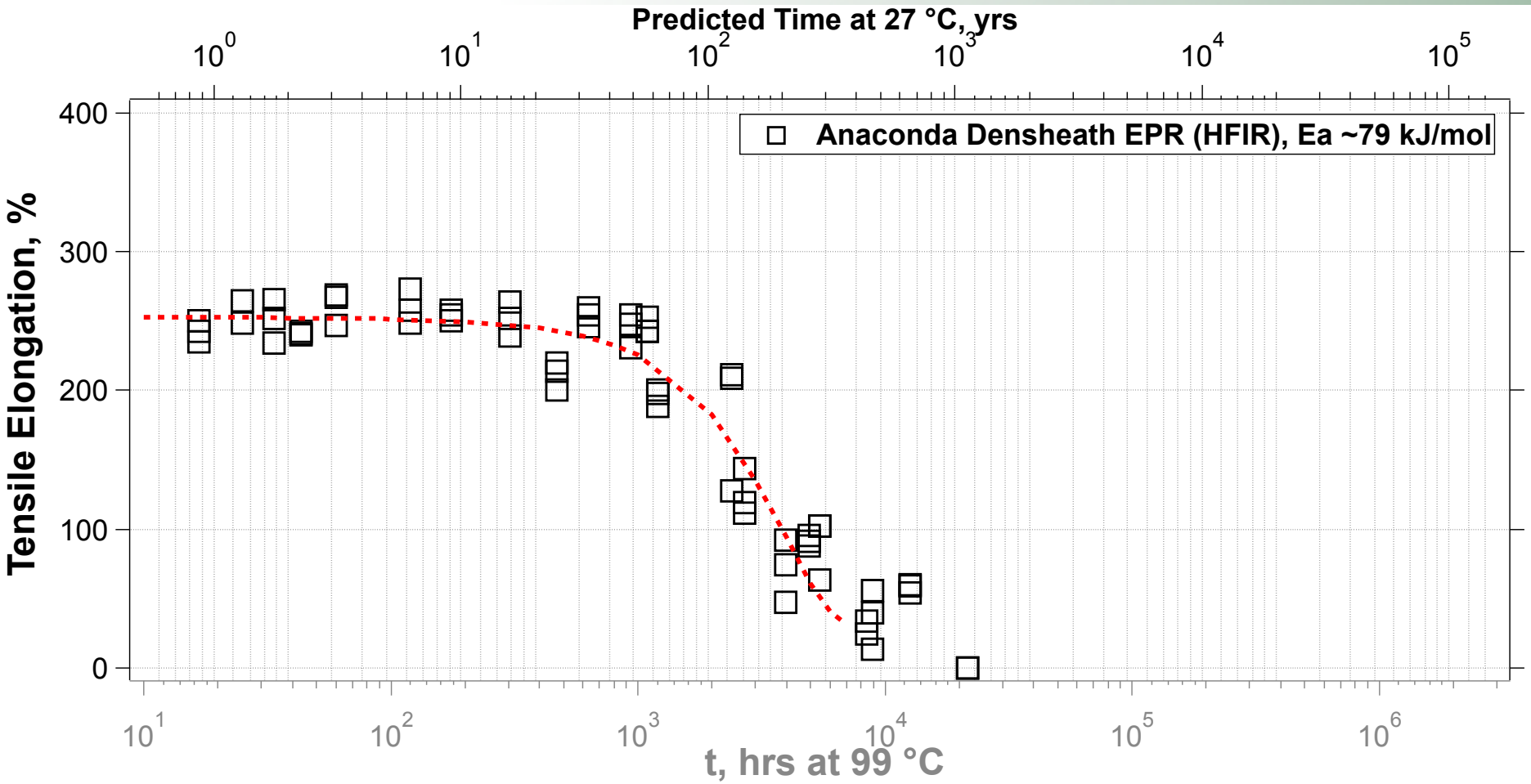
The Expanded Materials Degradation Assessment is an NRC-DOE Joint Effort

- **The EMDA is a Gap Analysis of Key Materials Degradation Modes, and expands on the PMDA activity (NUREG/CR-6923) to encompass broader systems and longer lifetimes**
- **A world-class group of panelists was assembled for EMDA**
- **The Phenomena Identification and Ranking Technique (PIRT) process was used to identify safety-relevant phenomena**
  - Captures current knowledge base
  - Identifies gaps in knowledge for a component or material system that must be resolved.
  - Identifies and prioritizes research needs and directions
- **Covers core internals and primary piping, pressure vessel, concrete, and cabling**
- **The final report will be issued as a NUREG**



Example for one specific set of conditions

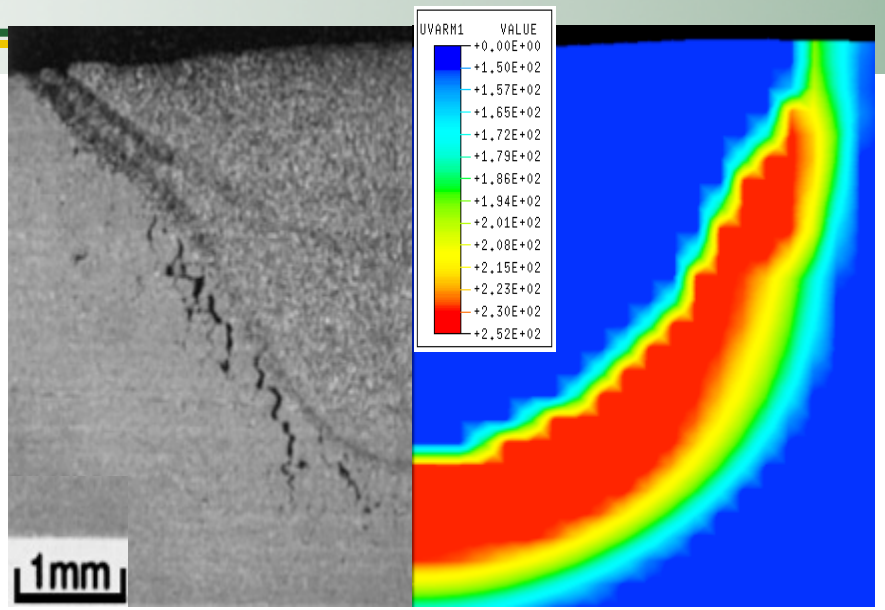
Accelerated aging on service cable materials is an important component of cable R&D

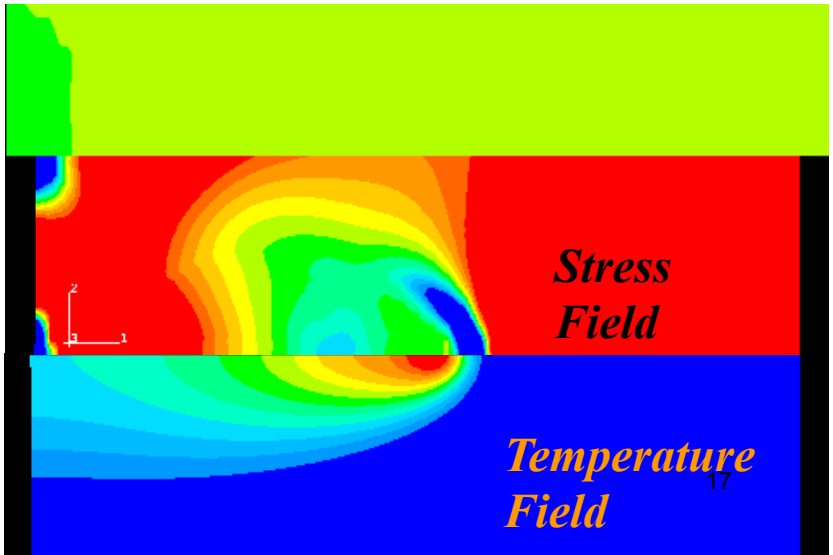


Anaconda Densheath EPR cables returned from service at HFIR at ORNL (~45 yrs of age, T_{avg} ~27 °C, RH ~70%). These cables were subjected to further thermal aging to elucidate their remaining tensile properties

Advanced Welding R&D May Provide Solutions to Long-Standing Areas of Concern

- **Residual stress-modeling provides insights into long-term performance and cracking resistance**
- **Current research in advanced weldments is jointly funded by DOE and EPRI**
  - Survey of present state of the art of hybrid welding processes
  - Development of advanced computational model for hybrid welding processes
  - Develop a science-based hybrid laser weld processing model to optimize the weldability of irradiated materials
  - Develop experiment methodology for direct measurement of transient high-temperature temperature and stress history during welding
- **Dedicated welding hot cell at ORNL will be commissioned in FY-14**
- **Technology will be transferred to industry in the near term**





The Decommissioning of Zion Units 1&2 Provides an Opportunity to Examine Service-Aged Materials

- **ORNL is coordinating and contracting activities with Zion Solutions**
- **In collaboration with the U.S. NRC, EPRI, and others, a list of materials for "harvesting" has been compiled and feasibility examined**
- **Structures and components of interest:**
  - Thru-wall RPV sections
  - Cabling
  - Concrete bore samples
- **The LWRS Program continues to seek additional opportunities for harvesting materials from nuclear power plants**

Overview of Materials Aging and Degradation Pathway Deliverables in FY-13 IPP

2013
- Expanded Materials Degradation Assessment; gap analysis of key materials degradation modes
- Concrete database in public domain
- Examination of Reactor Surveillance Materials including Palisades Reactor High Fluence Materials

2015-2017
- Model for transition temperature shifts in RPV steels
- Predictive capability for swelling in LWR components
- Predictive model for Ni-base alloy SCC susceptibility
- Predictive model for cable degradation
- Model for environmentally assisted fatigue in LWR components

2018 – 2022
- Prototype of concrete NDE system
- Transfer of weld repair technique to industry
- New NDE technology for RPV components
- Predictive model for IASCC susceptibility

2022 – 2026
- Characterization of RPV sections following annealing and re-irradiation
- Full code-qualified package for advanced replacement alloys

Harvesting service materials from active or decommissioned NPPs

Transfer of Technology to the Nuclear Industry – Materials Aging and Degradation Pathway

- **The Materials Aging and Degradation Pathway is working closely with EPRI**
  - The Pathway participates in EPRI's upkeep of the Materials Degradation Matrix
  - EPRI has participated in the LWRS/NRC/EMDA project as panelists in all major technical areas
  - All of the activities underway in the LWRS Program appear in the EPRI Issues Tracking Table which is updated periodically with input from EPRI utility advisors
  - Research tasks are designed to supply the data that will be used to inform and update Aging Management Plans
- **Many research activities are being done jointly with industry as collaborations with cost-sharing agreements**
- **Research results are disseminated via a variety of technical meetings, conferences, and program reports, many of which are available on the LWRS Program website (www.inl.gov/lwrs)**
- **The NEI Roadmap on Subsequent License Renewal (SLR) will identify what information is needed for SLR (from the point of view of industry), and the timeline for when that information is needed**
  - Once available, LWRS activities will be tied to the Roadmap schedule and documented in an LWRS Program report

Risk Informed Safety Margin Characterization Pathway

- **Support plant decisions for risk-informed margins management to support improved economics, reliability, and sustain safety of current nuclear power plants**
- **Goals of the Risk Informed Safety Margin Characterization (RISMC) Pathway:**
  - Develop and demonstrate a risk-assessment method coupled to safety margin quantification that can be used by nuclear power plant decision makers as part of their margin recovery strategies
  - Create an advanced "RISMC toolkit" that enables more accurate representation of nuclear power plant safety margins
- **With RISMC, we estimate how close we are (or not) to the event, not just the frequency of the event, providing information on how safety margins can be improved**

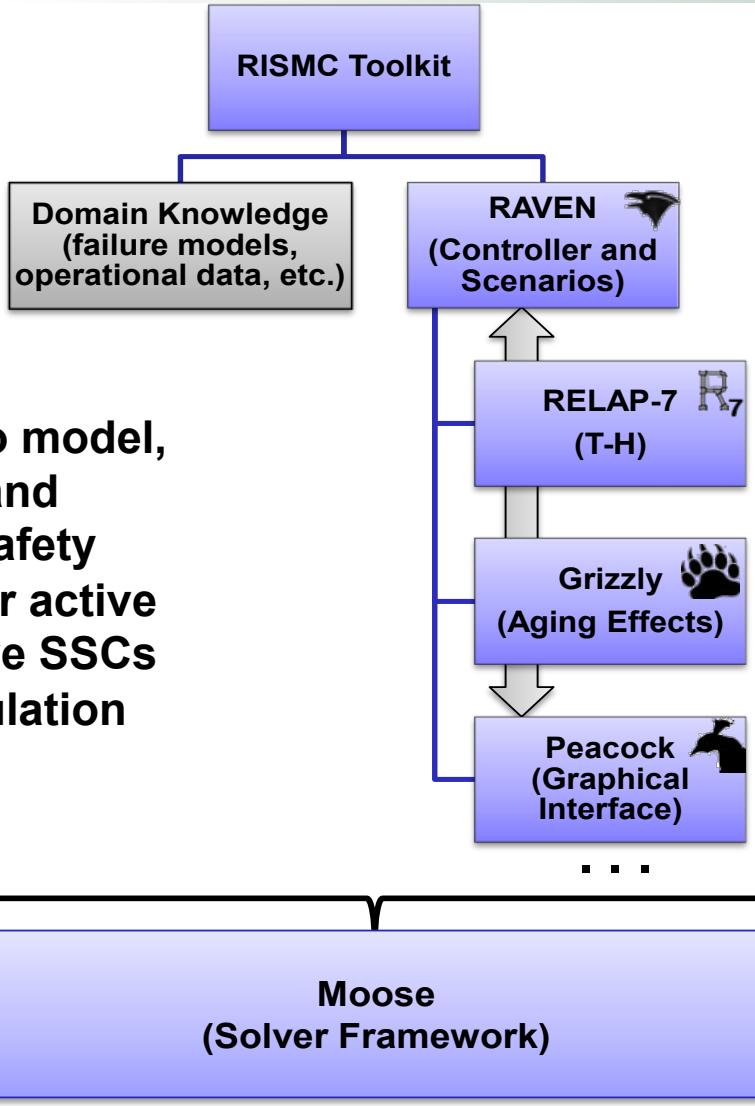
Margin Management Techniques

Determine methods to model, measure, and maintain margins for active and passive SSCs for normal and off-normal conditions

Develop techniques to conduct margins analysis, including methodology for carrying out simulation-based studies of safety margins

RISMC Toolkit – Supports Margin Management Techniques and Decisions

The RISMC Toolkit is being created to avoid the issues and limitations with legacy tools

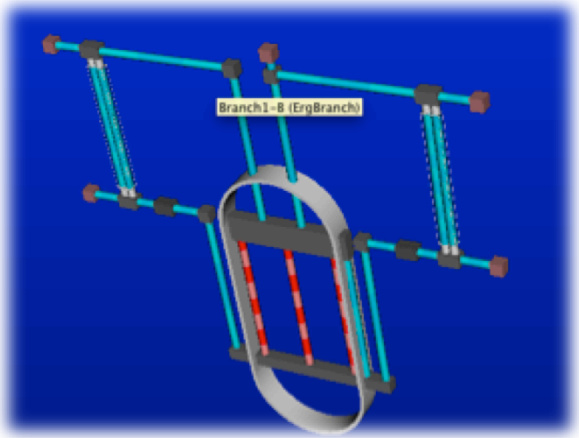


Note: V&V is essential for acceptance of new tools

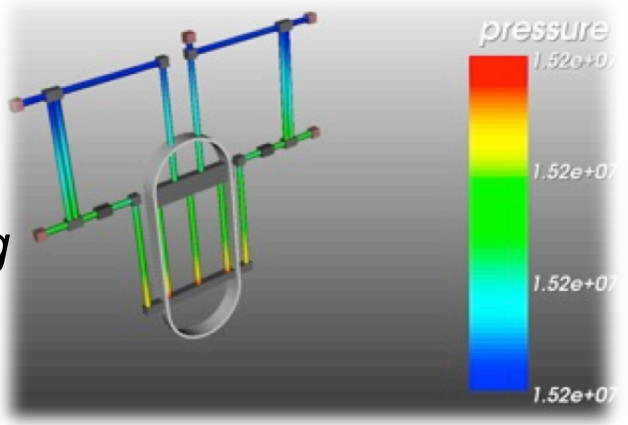
Methods to model, measure, and maintain safety margins for active and passive SSCs using simulation

MOOSE – Multiphysics Object Oriented Simulation Environment

Graphical User Interface Overview



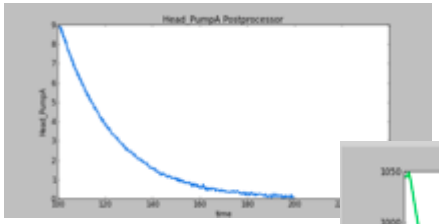
Interactive 3D view of the plant



Online monitoring of the solution

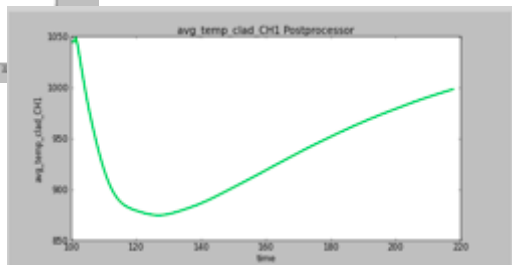
Increase in the modeling capabilities should be paired with more powerful handling tools to help the user exploit all features

- *Less prone to input errors*
- *Shorter learning curve*
- *Better understanding of driving physics*



Online monitoring of plant signals

Pump head



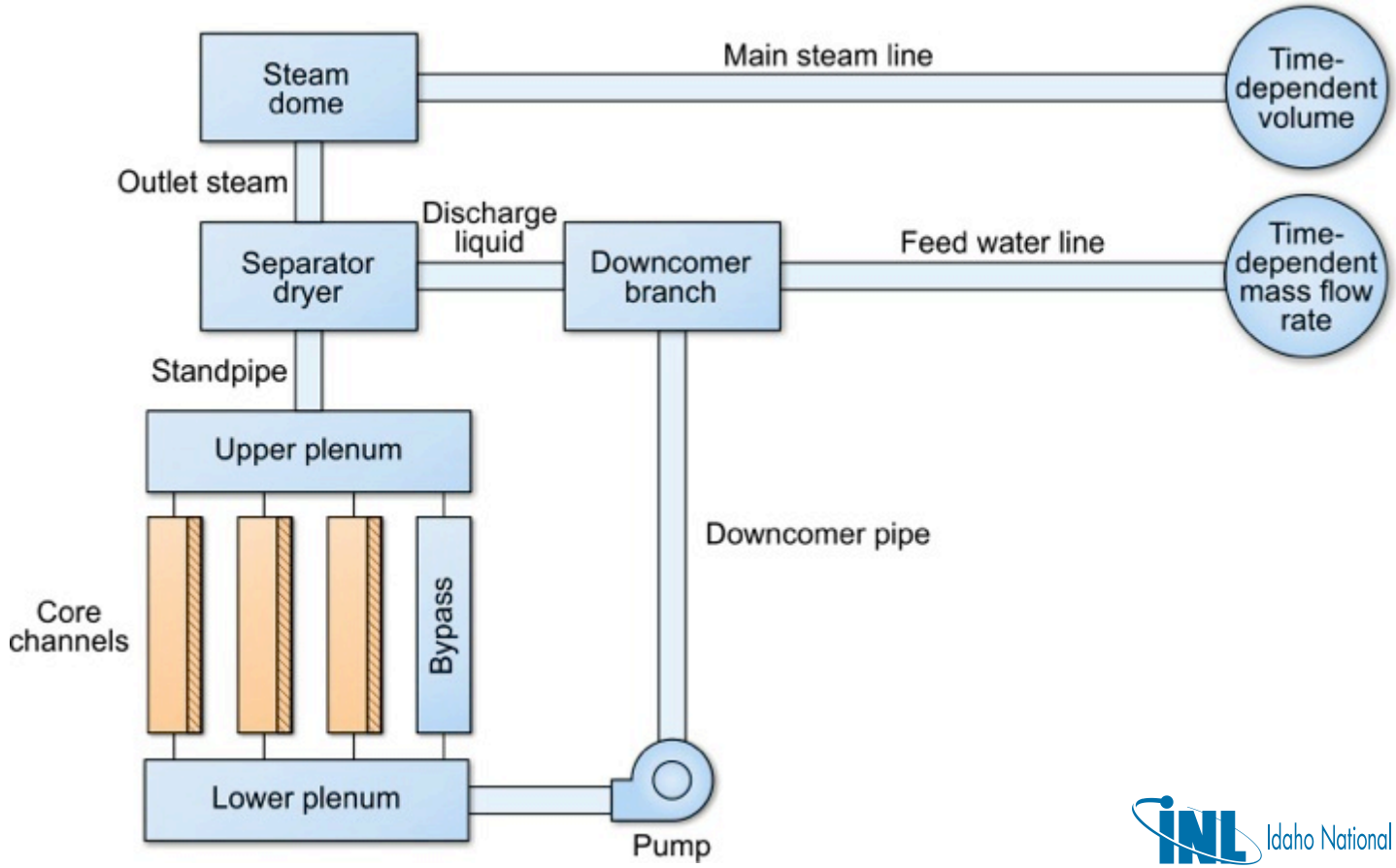
Clad temperature

RELAP-7 Development Schedule

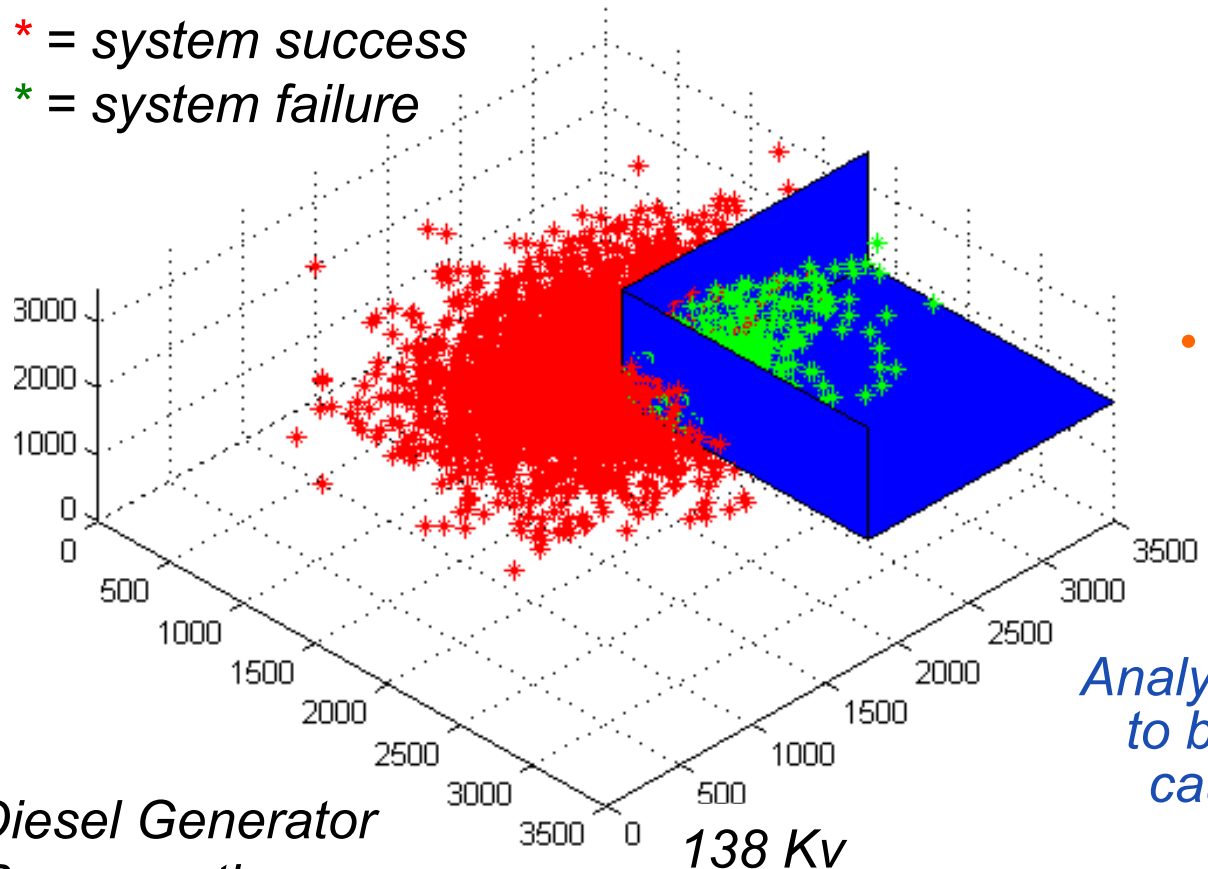
FY 2012	FY 2013	FY 2014	FY 2015 and beyond
- 3 equation single phase - Heat structures - Basic components	-7 equation two phase flow - Additional relevant components and physics for SBO	- Develop the full set of components to perform SBO for a BWR - Prepare the code for external release	- Develop and upgrade closure laws. Improve physical modeling of equation parameters - Extend the number of available components
Demonstration of a steady state PWR simulation	BWR SBO simulation on simplified system with relevant components	- Initial beta release - SBO for a BWR with Mark I containment	- Comprehensive Verification & Validation (V&V) & Uncertainty Quantification (UQ) - Delivering a large set of validating benchmarks

Two-Phase Flow Capability is Operational in RELAP-7

- **Demonstrated the integration of two-phase flow components for a simplified BWR loop**



Limit Surfaces From the Monte Carlo Station Blackout (SBO) Demo



- *Limit surfaces are mathematical constructs that separate the input space between regions leading to success or failure*
- *Plot assumes $T_{C,fail}$ =1477 [K]*

Analysis of limit surface leads to better understanding of cause-effect relationship

Overview of RISMC Pathway Deliverables in FY-13 IPP

2013

- Demonstrate RELAP-7 two-phase flow capabilities via analysis of station black out using simplified BWR geometry
- Demonstrate Grizzly (component aging model) on RPV

2014-2017

- Margins analysis techniques are sufficiently mature to enable industry to conduct margins quantification exercises for their own plants including simulations using RELAP-7/RAVEN/Grizzly
- Grizzly can model aging of steel (embrittlement) and aging of select concrete
- RELAP-7 validated against an accepted set of data
- Demonstrate RISMC on selected case study
- Assess leading accident resistant fuel technologies

2018-2020

- RAVEN/RELAP-7/ Grizzly and the margins analysis techniques are an accepted approach for safety analysis support to plant decision-making, covering analysis of design-basis events and events within the technical scope of internal events probabilistic risk assessment

Transfer of Technology to the Nuclear Power Industry – Risk Informed Safety Margin Characterization Pathway

- **RISMC Methodology and Toolkit is being developed together with EPRI**
- **Research results are disseminated via a variety of technical meetings, conferences, and program reports, many of which are available on the LWRS Program website (www.inl.gov/lwrs)**
- **Industry is the targeted users group for RISMC Tools**
  - Risk Informed Margin Management supports decisions on long-term operation
- **"Friendly testers" are being sought in FY-14**
  - The RISMC tools will be made available to industry volunteers who will use the tools and provide feedback to the LWRS Program
- **A "User's Group" is being considered to support Toolkit maintenance and provide a community-of-practice**

Instrumentation, Information, and Control (II&C) System Technologies Pathway

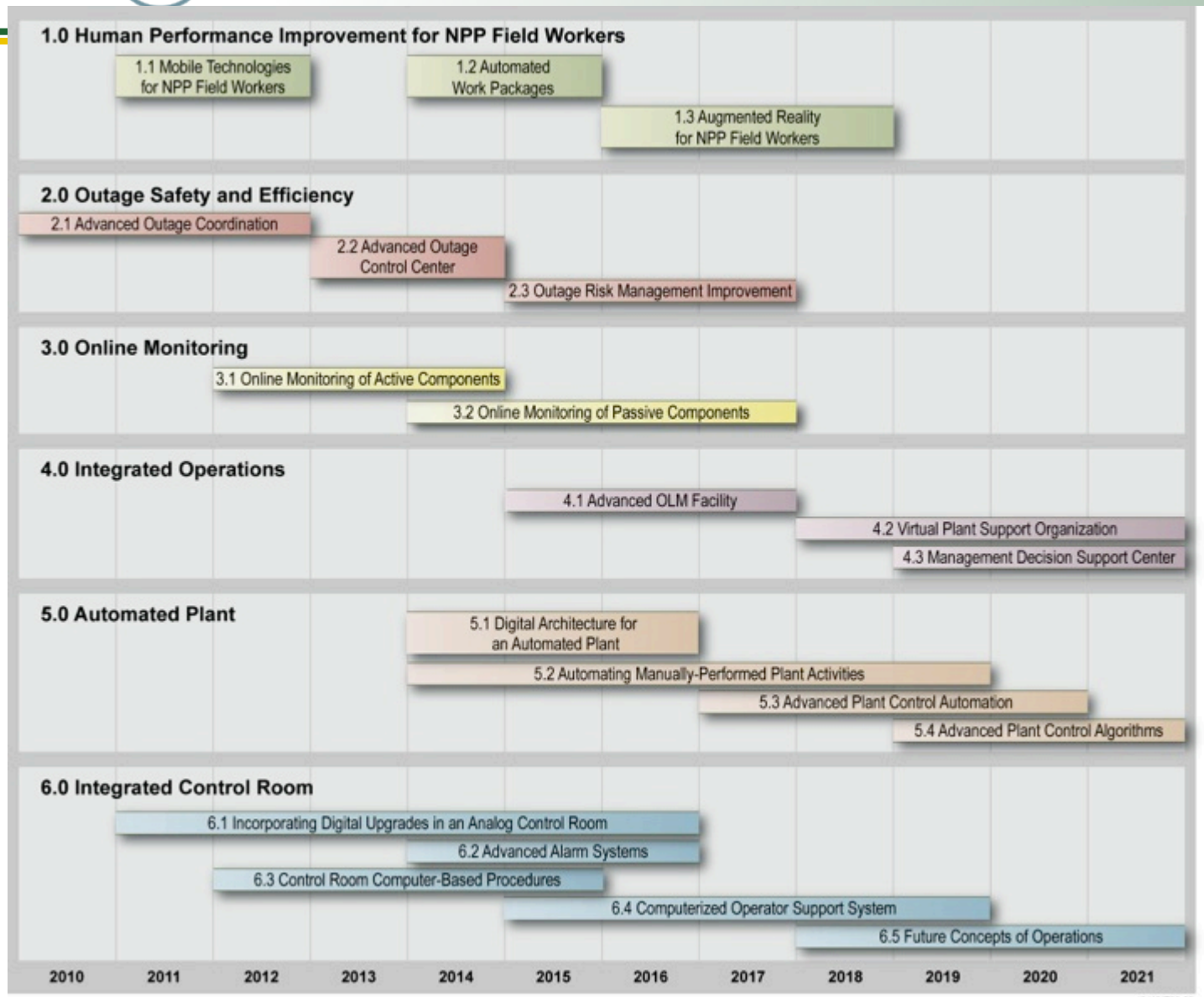
- **Develop, demonstrate, and enable the deployment of new digital technologies for instrumentation and control architectures**
  - Significantly reduce the technical, financial, and regulatory risk of instrumentation, information, and control system modernization by demonstrating the new technologies and operational concepts in an actual nuclear power plant setting
- **Provide monitoring capabilities to enhance the continued safe, reliable, and economic operation of the nation's operating nuclear power plants**
- **Develop capabilities to support long-term nuclear power plant operations and management**

II&C Pathway Strategy

- **The technologies are demonstrated in nuclear power plants under controlled circumstances to provide validation**
  - A series of pilot projects is underway at host utilities
  - A pilot project is small enough to be undertaken by a single utility, demonstrates a key technology or outcome, and supports scaling that can be replicated and used by other plants
- **The Human Systems Simulation Laboratory provides an advanced simulation facility to validate concepts that cannot practically be demonstrated in a nuclear power plant until they are validated (e.g., control room changes)**
  - Reconfigurable simulator
  - Can be linked to a virtual reality system
  - Study human performance

The Human Systems Simulation Laboratory at the Idaho National Laboratory

Technologies are Developed and Demonstrated Through a Series of Pilot Projects



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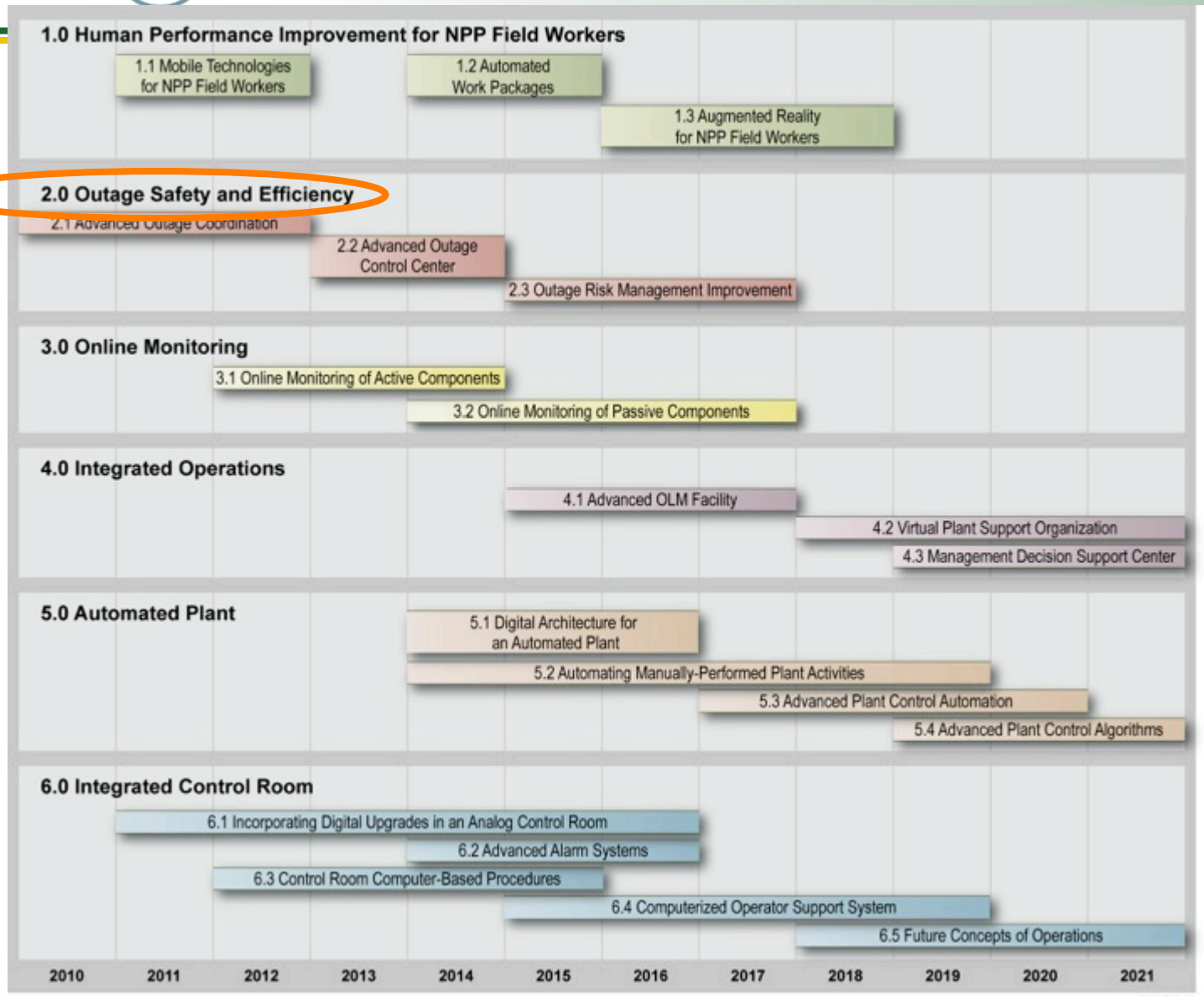
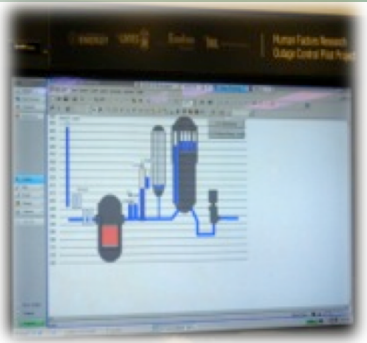


Outage Safety and Efficiency

- **Outage efficiencies provide the opportunity to improve capacity factor and nuclear safety margin**
- **Outage execution currently makes minimal use of technology in coordinating > 10K plant activities in a span of 3-4 weeks**
- **Three pilot projects: advanced outage coordination, advanced outage control center, and outage risk management improvement**
  - Provides technology to support real-time status determination and decision making
  - Provides modern outage control centers that are integrated with technology
  - Provides outage risk management technologies to improve control improve work activities interactions with changing plant configurations



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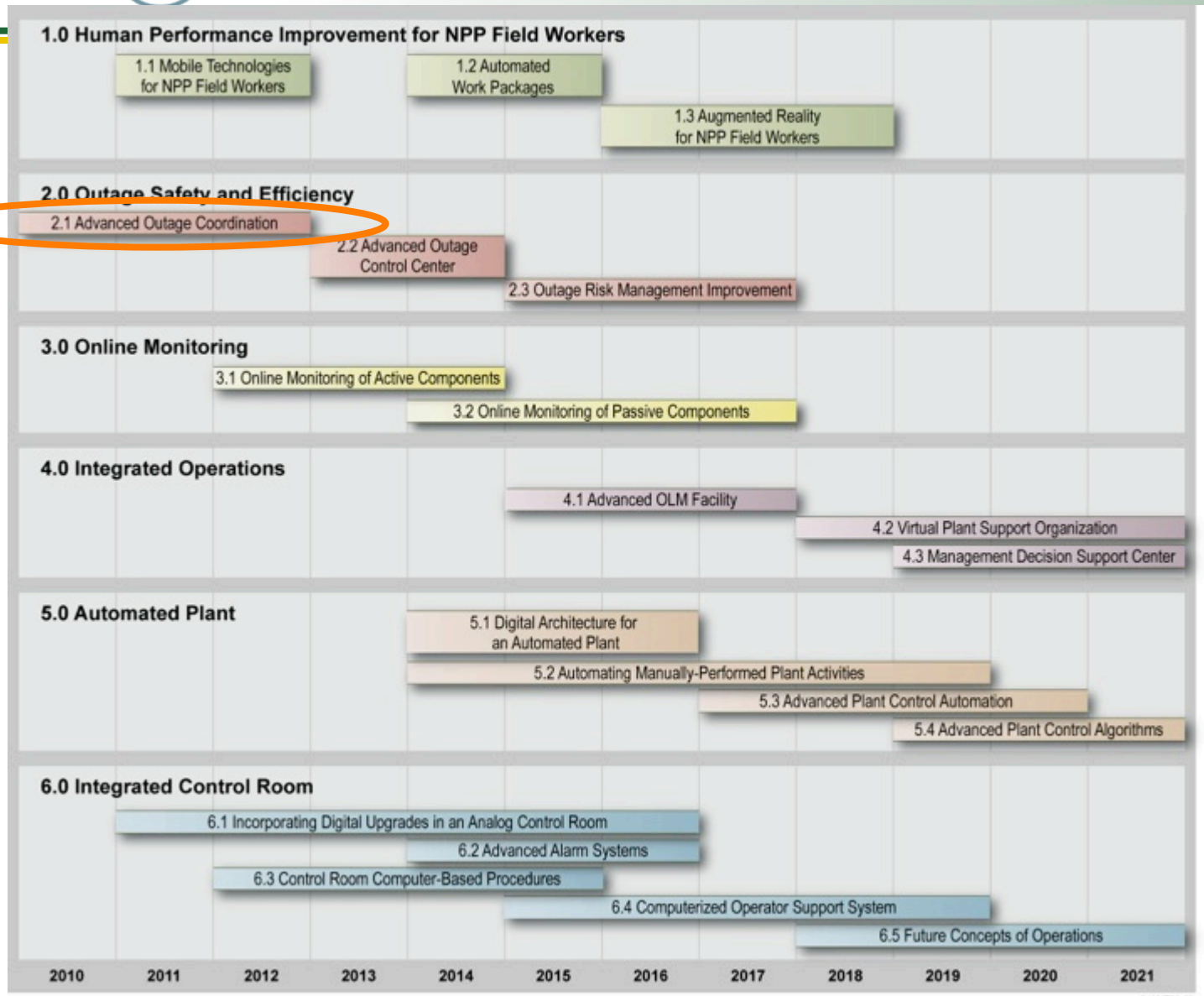
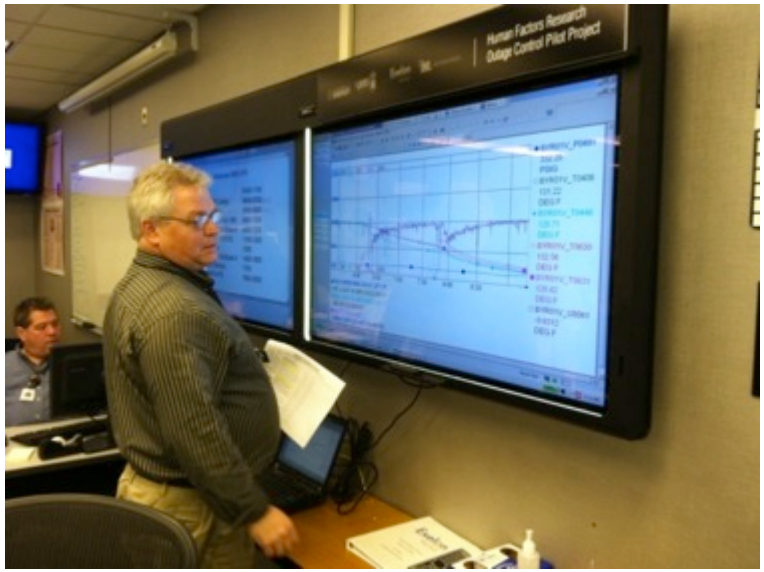


Advanced Outage Coordination

- Technology deployed during two successive outages at Exelon's Byron Nuclear Station
- Information exchange between the Outage Control Center and the Work Execution Center
- Continuous archival of issue resolution information
- Saves outage managers two hours per day in reduced time to coordinate outage issues
- Exelon implementing technologies through vendors at 7 units



Work performed by INL together with plant personnel

Overview of II&C Pathway Deliverables in FY-13 IPP

2013

- Gap analysis for integrating plant information
- Field studies of automated work package prototype technologies for NPP work processes
- Technologies for advanced outage control center

2014-2016

- Technical report on advanced alarm management system in a NPP control room
- Publish a technical report for an advanced outage control center informed by human factors studies
- Technical report for computer-based procedures
- Demonstrate augmented reality technologies for visualization of real-time plant parameters for mobile plant workers

2017-2019

- Technical report on augmented reality technologies for NPP field workers
- NPP operating model and organizational design quantifying the efficiencies that can be realized through highly automated plant activities using advanced digital technologies

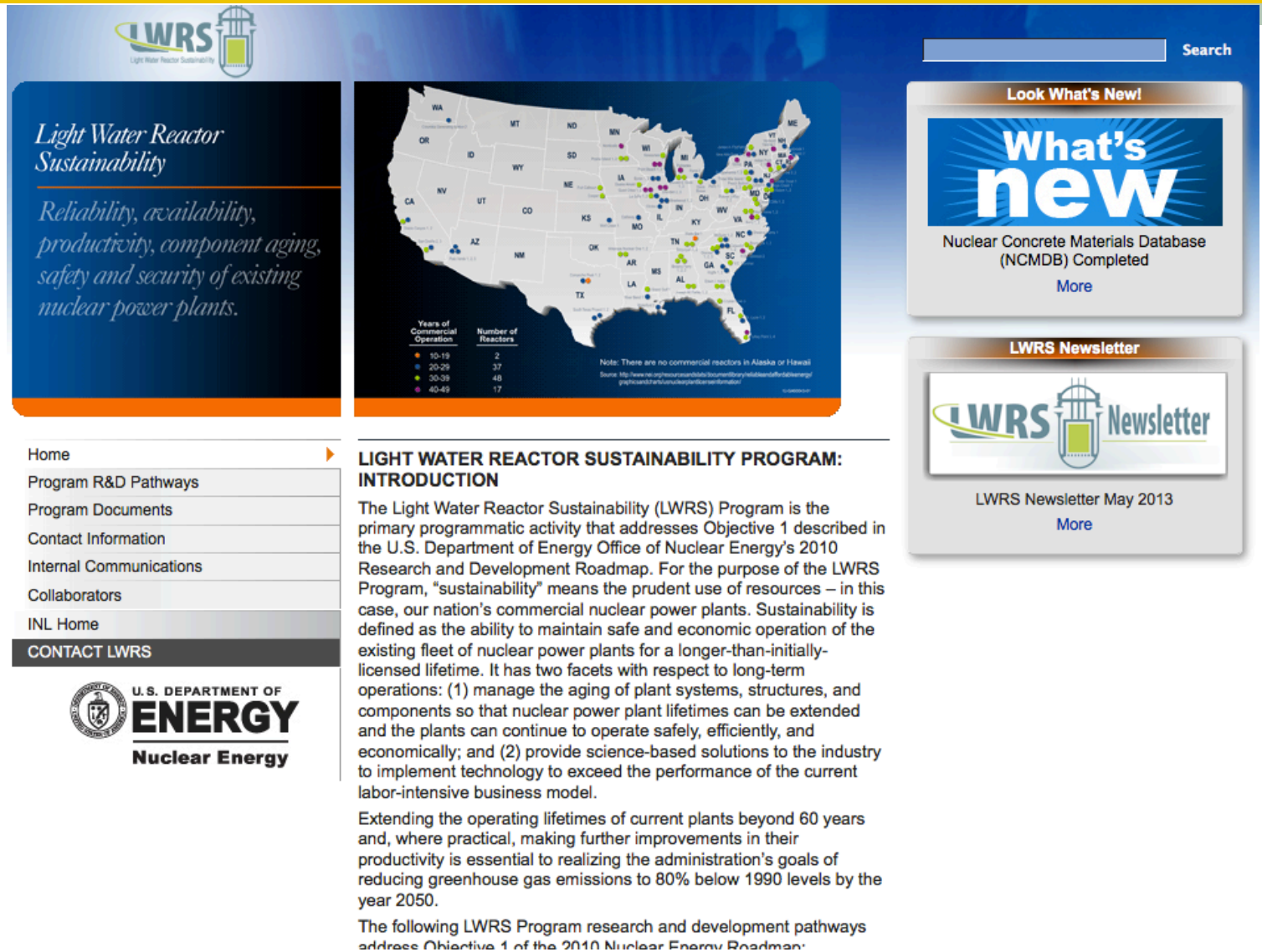
2020-2021

- Technical report for management decision support centers consisting of advanced digital display and decision support technologies

Transfer of Technology to the Nuclear Power Industry – Instrumentation, Information, and Control System Technologies Pathway

- Guidance and technical bases for guidelines will be published for each of the areas of enabling capabilities, incorporating the specific technologies and technical reports produced under each of the pilot projects for the respective areas
- EPRI will develop and publish these consensus guidelines, using their standard methods and utility interfaces to develop the documents and validate them with industry
- The LWRS Program Advanced II&C Pathway will support this effort by providing the relevant information and participating in the development activities
- In addition, research results are disseminated via a variety of technical meetings, conferences, and program reports, many of which are available on the LWRS Program website (www.inl.gov/lwrs)

The LWRS Program Website Provides a Range of Program Information (www.inl.gov/lwrs)



Light Water Reactor Sustainability Program

- Utilizing the unique facilities and capabilities in the U.S. government laboratory system, the Department of Energy Light Water Reactor Sustainability Program is providing research results in the near- and longer-term to provide science-based data, methods and models to support the long-term operation of the nation's nuclear power plants
- This information will be available to the nuclear industry and the Nuclear Regulatory Commission to inform decisions on extended plant operation

Helping to Sustain National Assets